Design of an Armament Wing for a Light Category Helicopter

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Abstract: The objective of this research is to study the feasibility of an armament wing as a weapon carrier for a light category helicopter of 3000 kg class to increase the aerodynamic efficiency of the helicopter. Modern attack helicopters need better agility, maneuverability, and diving characteristics, higher ‘g’ capability and increased speed. Many conventional and non-conventional ways are being used to improve the helicopter performance; which includes use of auxiliary engines, propellers and wings etc. A wing improves overall lifting effectiveness with increased velocity and improve the decreasing effectiveness of the main rotor in extreme cases (high altitude/high speed/more weight).

To install a wing on a light category helicopter, the aerodynamic design of the wing was taken up during this project work. Parameter estimation was carried out through hand calculations and by using a simulation program. Firstly, enormous literature was studied to figure out the type of the wing to be used on the helicopter. The literature survey included the statistical analysis of various class of helicopters with wings. The statistical analysis helped in choosing the area of the wing. To assess the performance of the helicopter with wing, a simulation program in the form of optimizer was required to estimate the overall behaviour of the helicopter throughout the flight regime (different AUW, speeds and altitudes). Subsequently, it is used to optimize the wing parameters (Incidence angle and location of the wing). This program calculates the forces and moments on the aerodynamic surfaces with 3 Dimensional effects. The final optimization of wing parameters was based on the performance of the wing at different speeds and altitudes. The overall helicopter behaviour in terms of controls angle, Attitudes and power was also considered to choose the final wing configuration. This research work includes the comprehensive analysis of aerodynamic design process for a light-category helicopter.

KEYWORDS

1. HAL- Hindustan Aeronautics Limited
2. NACA- National Advisory Committee for Aeronautics
3. Km/h - Kilo meter per hour
4. M/h - Meter per hour
5. AOA - Angle of attack
6. AOI - Angle of Incidence
7. L/D - lift by Drag
8. AR - Aspect ratio
9. S - Area
10. b - Span
11. C_L - Coefficient of lift
12. C_D - Coefficient of drag
13. C_m - Coefficient of moment
14. \rho - Density
15. V - Velocity
16. Deg – Degree
17. Kmph- Kilometre per hour
18. V_Y - Velocity w.r.t. best rate of climb
19. V_H – Maximum cruising speed

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7. Tail rotor collective cyclic
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I. INTRODUCTION
The research was carried out for a light category helicopter of 3 tonne weight class. The helicopter meets the requirements of both military and civil operators.

The general characteristics of light category helicopter are:
- Predominantly composite airframe with excellent crashworthy features.
- Composite main and tail rotor blades for excellent damage tolerance capability. Hinge-less rotor system for high agility and manoeuvrability of the helicopter.
- Advanced avionics suite with fully integrated smart multi-functional display and indigenously developed application software.
- Several dual redundant systems ensuring higher level of safety.

In this, we will introduce an armament wing in light category helicopter so that it can be used for attack/defence purposes and to increase the aerodynamic efficiency of the helicopter. In the coming period, there will be a wide improvement in helicopters regarding speed, range and other features. The basic features required for the attack helicopters are better agility, manoeuvrability and increased speed. Many ways have been implemented to improve the helicopter’s performance which includes, the use of auxiliary engines, wings etc. But by installing the wing, the helicopter’s overall lifting efficiencies with increased velocity and decreasing effectiveness of main rotor improves in extreme cases like high altitude, high speed etc.

**II. LITERATURE SURVEY**

The objective was to design the armament wing for light category helicopter. The basic requirement for designing the wing was the shape of the airfoil and airfoil nomenclature which was surveyed from ‘Fundamental of Aerodynamics by John D Anderson. The shapes of all the standards NACA airfoils are generated by specifying the shape of the mean camber line and then wrapping a specified symmetrical thickness around mean camber line. The NACA identified various airfoils shapes like NACA 4 digit series, 5 digit series and 6 digit series with the logical numbering system.

To design an armament wing, the research was done to select the suitable airfoil series. Out of various series like 4 digit, 5 digit, 6 digit, 7 digit, NACA 4 digit series was selected because the higher digit series(5,6,7) have more thickness than 4 digit series which can increase the weight of the wing and that can be a drawback in the performance of the helicopter as it is a light category helicopter. The NACA 4 digit series have a suitable thickness for such category. NACA 4 digit series aerodynamics coefficients were referred from ‘Theory of wing sections’ by IRA H. Abott.

IHS Jane’s, ‘All the world’s Aircraft Development and Production’ was referred to compare the span and chord of the different attack helicopters to select the wing area and aspect ratio was decided based on the statistical analysis.

So based on the above literature survey, the airfoils series and wing parameters were decided for the further analysis and parametric studies.

**III. ANALYSIS**

- **THEORETICAL CALCULATIONS**

In the first step the wing forces were calculated which were required to improve the helicopter’s performance. The 3-D forces and moments for a wing for different flight conditions were calculated by the airfoil theory. Aerodynamic coefficients of different NACA airfoils were used to calculate the forces and the moments generated by the wing in different flight regimes. By using the following formulas, aerodynamic forces and moments were calculated.

\[
L = \frac{1}{2} \rho v^2 S C_1 \quad (1)
\]

\[
D = \frac{1}{2} \rho v^2 S C_d \quad (2)
\]

\[
M = \frac{1}{2} \rho v^2 S C_m \quad (3)
\]

On comparing the dimensions of wing of few helicopters like Apache, Augusta, Bell etc., the average span and chord were considered. Using that span and chord, the approximate area of 2.737 m was considered for Light category helicopter.

- **SIMULATIONS:**

Simulation studies were also carried out to calculate to confirm the theoretical calculations. After confirming the trends and sensitivity w.r.t. different flight conditions, it was required to assess the performance of the helicopter with wing. The control angles, attitude and total power were estimated for different flight regimes i.e. hover, low speed handling, level flight. At sea level, the aerodynamic forces and moments were obtained at different angles for different speeds.
The prime objective of this study was to check the behavior of the helicopter with wing for different flight regimes.

IV. PARAMETRIC STUDIES

- EFFECT OF AEROFOIL:

The Aerodynamic forces and moments were calculated for different airfoils like NACA 4418, 4424, 4412 and 2412 considering respective aerodynamic coefficients ($C_l$, $C_d$, and $C_m$) at Mach 0 and Reynold’s number one lakh. Angle of attack of wing was a resultant of wing incidence angle (AOI), helicopter angle of attack and helicopter pitch angle. Helicopter angle of attack changes with respect to flight regime. However, it is fairly accurate to assume the angle of attack of the helicopter same as the helicopter angle of attack in level flight.

It is observed that for all the airfoils, lift was increasing with AOA and with specific stall angle of attack. The general outcome of theoretical analysis is listed below:

- Drag increases with the increase in AOI and AOA as shown in Table 1 & fig.1.
- Lift due to armament wing increases with the increase in AOI and AOA as shown in table 1 & fig.2.
- Pitching moment due to armament wing increases with the increase in the AOI and AOA as shown in Table 1 & fig.3.

<table>
<thead>
<tr>
<th>AOA (degree)</th>
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<th>$C_d$</th>
<th>$C_m$</th>
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<td>-5</td>
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Table 1: $C_l$, $C_d$ and $C_m$ of NACA series 4412
The overall performance of the wing was based on following aspects:

- **LIFT TO DRAG RATIO:**

An efficient airfoil produce the lift with the minimum of drag i.e. the ratio of L/D is a measure of aerodynamic efficiency of the airfoil. The L/D ratio of the complete flight vehicle has an important impact on its flight performance. For e.g. the range of the vehicle is directly proportional to L/D ratio. The higher the L/D the airfoil will be more efficient. Different aerofoils is given in Table 2. The calculation was based on maximum flight speed of the helicopter (V_H) at sea level. Based on this, out of all the above airfoils, NACA 4412 had highest value of L/D ratio as shown in fig. 4.

- **THE MAXIMUM LIFT COEFFICIENT:**

An effective airfoil produce a high value of C_L,max for a complete flight vehicle. The value of C_l increases linearly with the AOA until an AOA is reached when the wing stalls, the lift coefficient reaches a peak value, and then drops off as AOA is further increased. Therefore, NACA 4412 airfoil was resulting in the highest value of C_L,max.

<table>
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<tr>
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**Table 2:** L/D Ratio for different airfoils at different AOA (degree)

**Figure 4:** Comparison of different airfoils

- **EFFECT OF ASPECT RATIO ON WING:**

The induced drag coefficient for a finite wing with general lift distribution is inversely proportional to aspect ratio. The primary design factor for minimizing the induced drag is the ability to make the aspect ratio as large as possible.

AR = b^2/S

Low AR (high induced drag)

High AR (low induced drag)
During this research, the wing area and aspect ratio (Fig. 5) was decided based on the statistical analysis of contemporary helicopter. The wing dimensions are given below:

- **Wing Span**: 3.9 m Tip
- **chord**: 0.526 m Root
- **Chord**: 0.878m
- **Area**: 2.737m
- **Aspect Ratio**: 5.555

**Figure-5: Schematic of Low and High Aspect ration wing.**

- **EFFECT OF WING INCIDENCE ANGLE AND SPEED:**

  Parametric studies were carried to optimize the wing incidence angle at different speeds. The primary aim was to get the lift of at least 10-12% of the all up weight. That amounts to be around 3000 to 4000 N. This criteria was important from getting higher speed point of view. It is also worth to be noted that helicopter in this weight range being designed for Indian conditions may not require very high speed. Another criteria was to get better range and endurance and to check the wing performance from 
  
  \[ \text{VY} \text{ (velocity } w.r.t \text{ best rate of climb) to } \text{VH} \text{(maximum cruising speed).} \]

  This range of speed covers the Best Range and Best Endurance speed. It was also required to have lesser control angles, power and similar pitch attitude of the helicopter compared to the helicopter without wing. In addition to all these facts, the wing lift should also increase with speed and not flattened out or stalled. There was also a drastic reduction in the amount of lift being calculated by simulation studies compared to theoretical (hand calculations) calculations. This can be attributed to the 3-D effects of wing itself and interference effect of wing with other helicopter components. However, the overall aerodynamic sense regarding the ratio of lift and drag was same for simulation studies and theoretical calculations.

  Considering everything mentioned above, the wing incidence can be chosen as 12 to 15 deg. The wing with 12-15 deg of incidence angle would off-load the rotor in the speed range of \( \text{VY} \) (velocity \( w.r.t \) best rate of climb) to \( \text{VH} \) (maximum cruising speed). However, 12-15 deg of wing would have higher control angle and power requirement at \( \text{VH} \).

  Another fact which might be critical during the installation of wing with weapons on the helicopter is the ground clearance. At this point, it is quite premature to decide anything on the wing incidence angle based on the ground clearance.

Overall, a wing with 12-15 deg of incidence angle would give benefit in the range of \( \text{VY} \) with a penalty in \( \text{VH} \). Alternatively, using a wing with 0 deg incidence angle would have no loss add no benefit in the entire flight regime. However, this is not recommended. All in all, it is recommended to use 12-15 deg of wing incidence angle for a light category helicopter of 3000 kg weight category.

**Figure-6: AOA vs Speed Variation**

**Figure-7: Lift at various airspeed**

**V. CONCLUSION**

1. For installation of armament wing in Light category helicopter, NACA 4412 airfoil was found suitable on the basis of \( \text{L/D} \) ratio. This was providing maximum lift and minimum drag.

2. The wing incidence angle was selected to be 12-15 degree based on the benefits only at lower speeds. This type of wing can be used when slight reduction in maximum level flight speed is acceptable.

3. The wing incidence of 0 deg incidence angle
gives benefit in terms of helicopter power and control angles at lower speeds without any loss at maximum level flight speed with. This type of wing would serve the purpose of weapon carrier with improvement in overall helicopter range and endurance.

4. Control angle and Power requirements were less with wing on the helicopter compared to the helicopter without wing.

5. Power requirement reduces with higher wing incidence angles at the speed range of $V_Y$ to $V_H$.

6. Decrease in maximum level flight speed or higher power requirement at maximum level flight speed was observed.

7. Increase in Range and Endurance is expected by installing a wing on the light weight Helicopter of 3000 kg class.

8. Wing location can be chosen slightly forward to the C.G. of the helicopter to get higher nose up moment to reduce negative pitch angle of the helicopter.

VI. REFERENCES

- IHS Jane’s, all the world’s Aircraft Development and Production. Editor in chief: Paul Jackson FRAES.
- “Theory of wing sections” by IRA H. ABOTT and ALBERT E. VON DOENHOFF, Research engineer NASA.